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# Multi-bunch injection for SSRF storage ring*

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The multi-bunch injection adopted at Shanghai Synchrotron Radiation Facility (SSRF) increases the injection rate greatly, with much less injection time than that of single bunch injection. It reduces massively the beam failure time during users' operation and prolongs the pulsed injection hardware lifetime. In this paper, the scheme to produce multi bunches for the RF electron gun is described. The filling result and beam orbit stability for top up operation is discussed.

Keywords: Multi-bunch, Injection, Shanghai Synchrotron Radiation Facility (SSRF)

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## I. INTRODUCTION

A third generation light source is a working horse for X-ray science. The beam availability time can be 98% for advanced light sources. Great efforts have been made to increase the mean time between failures (MTBF) and to decrease the mean down time (MDT) to satisfy users' requirements. An effective method to decrease MDT is to increase the injection rate.

Table 1 lists the injection status for seven 3$^{rd}$ generation light sources. Single bunch injection scheme is used by six light source. The advantage of single bunch injection is that bunch charge can be kept highly uniform for top up operation which benefits beam orbit stability, and when orbit stability is approaching the sub-micron level, the beam position monitors (BPM) are sensitive to the filling pattern [1].

TABLE 1. Injection status of 3$^{rd}$ generation light sources [2–8]

| Facilities | Injection mode | Booster repetition rate (Hz) |
|---|---|---|
| Diamond | Top-up, single bunch | 5 |
| Soleil | Top-up, single bunch | 3 |
| Spear 3 | Top-up, single bunch | 10 |
| ALS | Top-up, multi bunches | 1 |
| SLS | Top-up, single bunch | 3 |
| Spring8 | Top-up, single or trains | 1 |
| APS | Top-up, single bunch | 2 |

Shanghai Synchrotron Radiation Facility (SSRF) is an advanced 3$^{rd}$ generation light source, with a storage ring of 432 m in circumference, running 3.5 GeV electron beam bunches with a natural emittance of 3.9 nm rad. The injector includes a 150 MeV linac, and a 3.5 GeV booster that operates at a repetition rate of 2 Hz. For single bunch injection, filling the storage ring from 0 mA to 240 mA usually takes around 20 minutes. This is limited by beam charge emitted from cathode of the RF gun and by the booster repetition rate. For the top up operation, filling 1 mA takes 15 seconds, injecting 30 tiny single bunches to where bunch charge is the lowest in the ring, keeping the filling pattern uniformly.

In 2014, SSRF started investigating multi-bunch injection scheme to reduce the injection time. In this paper, we report the study in details.

## II. MULTI BUNCHES GENERATION FOR THE LINAC

To generate multi bunches, the pulsed voltage of grid cap has been stretched from 3 ns to 12 ns using reflecting cables. The method is pretty simple and economical. The measured voltage pulse is shown in Fig. 1. The stretched pulse creates a 12-ns long electron bunch from the electron gun. The long bunch is sent to a 500 MHz sub harmonic buncher, at the exit of which 5 or 6 bunches are formed with bunch length of 300 ps at energy of 10 MeV. The bunches are accelerated to 157 MeV by the linac through 4 travelling wave tubes.

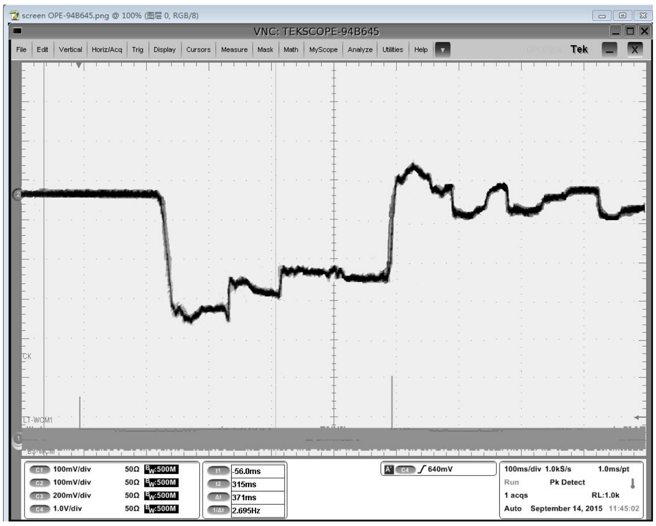


Fig. 1. Measured voltage pulse on the grid cap (The voltage after reflection gets decreased).

Energy divergence of the bunches is 0.74% (Fig. 2). Although, this is worse than that of the single bunch mode

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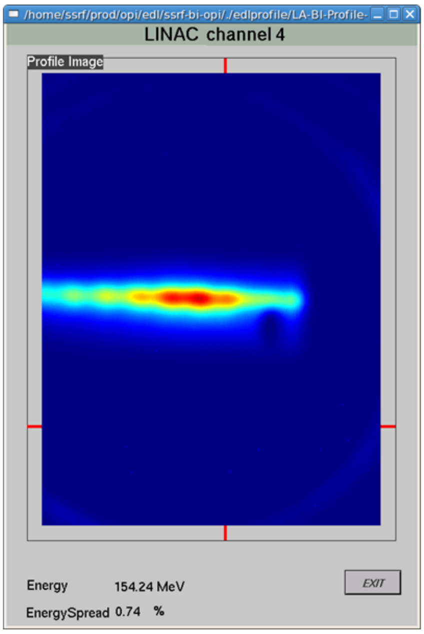


Fig. 2. (Color online) Measured energy spread at the end of the linac for multi bunches.

(0.5%), energy acceptance of the booster injection (2.0%) permits such an energy divergence of the multi bunches, which ensures a large injection efficiency for the booster.

## III. TOP UP INJECTION EFFICIENCY AND BUNCH CHARGE UNIFORMITY

For top up operation, injection efficiency from booster to storage ring is a critical parameter for dosimetry concern. The injection efficiency interlock threshold for SSRF is 50%, below which the top up injection shall be stopped.

For multi-bunch injection, the situation is not much different from single bunch injection. The energy deviation among the bunches from the linac can be fully damped during energy ramping process by the booster. Quality of the bunches extracted from the booster depends on the booster conditions. Pulses of the booster extraction kickers and the storage ring injection kickers have wide flat tops of around 125 ns, while the multi bunches expand a time duration of just 10 ns. So, the multi bunches receive a uniform strength kick ensuring an injection efficiency to be the same as single bunch injection. The injection efficiency of top up operation was measured at $>85\%$. A snapshot of injection efficiency is shown in Fig. 3.

To keep bunch charge uniform in multi-bunch injection mode is much more difficult than in the single bunch injection mode, where the lowest charge bucket can be picked out by a bunch current monitor (BCM). However, the top up injection control system will shot the injected bunch to the bucket, so the point to point filling is impossible. The methods for filling the current include random shooting, injection bunches to buckets in a sequence, and pick out the lowest

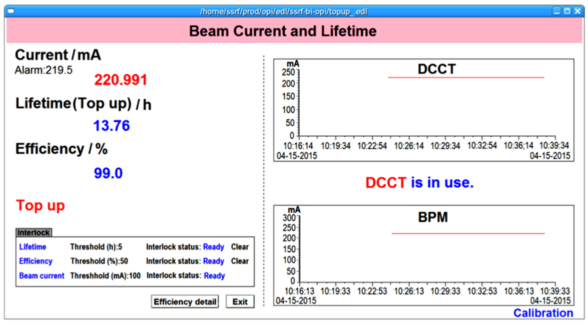


Fig. 3. (Color online) A snapshot of the machine status for top up operation.

charge bucket to fill, which is the best for charge uniformity in top up operation. The injected charge distribution of the multi bunches is shown in Fig. 4. It is important to shift the top up timing controller 2 ns later to inject the highest charged bunch to the bucket in order to hold the lowest charge.

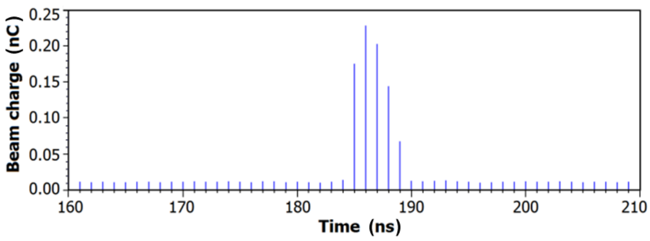


Fig. 4. (Color online) Injected multi-bunch charge distribution.

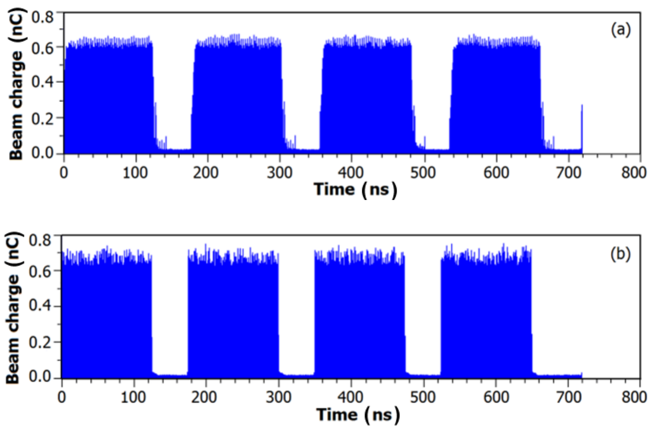


Fig. 5. (Color online) Bunch charge deviation during top up operation (Filling pattern $4 \times 125$ bunch-train, total bucket number 720).

The bunch charge deviation for multi-bunch injection is 3.3%, as shown in Fig. 5(a), therefore, the bunches at the two ends of the bunch trains are ignored since it is uncontrollable for multi-bunch injection and will not affect the BPMs greatly. As a comparison, the bunch charge deviation for single bunch injection is 5.0% [9] (Fig. 5(b)). The reason of a better bunch charge deviation for multi-bunch injection is that

the charge of an individual bunch for the multi-bunch injection scheme is smaller than that of the single bunch injection scheme.

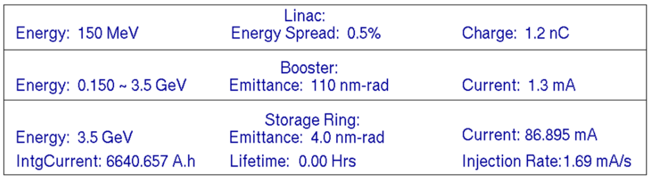


Fig. 6. (Color online) Injection rate of multi-bunch injection.

For multi-bunch injection, the injection rate can be over 1.6 mA/s (Fig. 6), while it is just 0.3 mA/s for single bunch injection. The filling time of 240 mA can be shortened from 20 minutes to 5 minutes. For top up filling, a single bunch injection takes 15 s, while it takes just 4 s in multi-bunch injection (For top up injection, the bunch charge is decreased by the focus solenoid after RF electron gun). Since the local closed bump injection orbit distortion is inevitable, shorten the injection time is better for users' experiments.

## IV. ORBIT STABILITY

BPM readings are sensitive to the beam current and filling patterns. For providing stable lights to users, light sources pursue top up operation so as to keep beam current and filling pattern constant. As shown in Sec. III, the filling pattern keeps constant during top up operation, so the BPM noise from filling pattern can be minimized.

The orbit feedback systems of SSRF are based on SVD algorism [10], which is used at other light sources. For SSRF, not all of the SVD singular values are used which makes the systems stable. The BPM reading errors from filling pattern are minimized as efforts mentioned in Sec. III. The 24-h orbit stability of the storage ring (measured at the end of a straight section) is as shown in Fig. 7. The RMS values for horizontal and vertical plane are 0.35 and 0.13 μm, respectively, while they are 0.26 and 0.25 μm in single bunch injection.

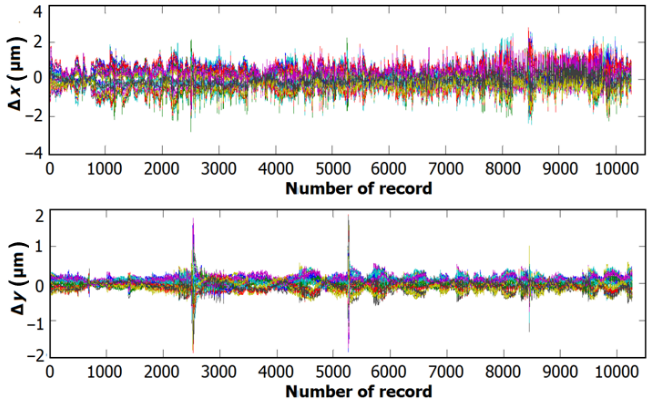


Fig. 7. (Color online) Injection rate of multi-bunch injection.

## V. CONCLUSION

The multi-bunch injection applied at SSRF shortens the injection time greatly, which deceases MDT, and the orbit distortion period for top up operation as well. This can surely prolong lifetime of the septum, kickers and other pulsed injection components, of which the lifetime is related to trigger frequency.

Orbit stability is important for light sources. Filling pattern should be carefully arranged for multi-bunch injection to keep the bunch charge uniformly, minimizing the BPM noises.

As most of the performances of multi-bunch injection are similar to or better than single bunch injection, the scheme has been conducted for users' operation.

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